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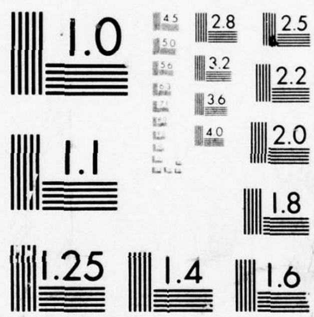

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REPORT 77-28

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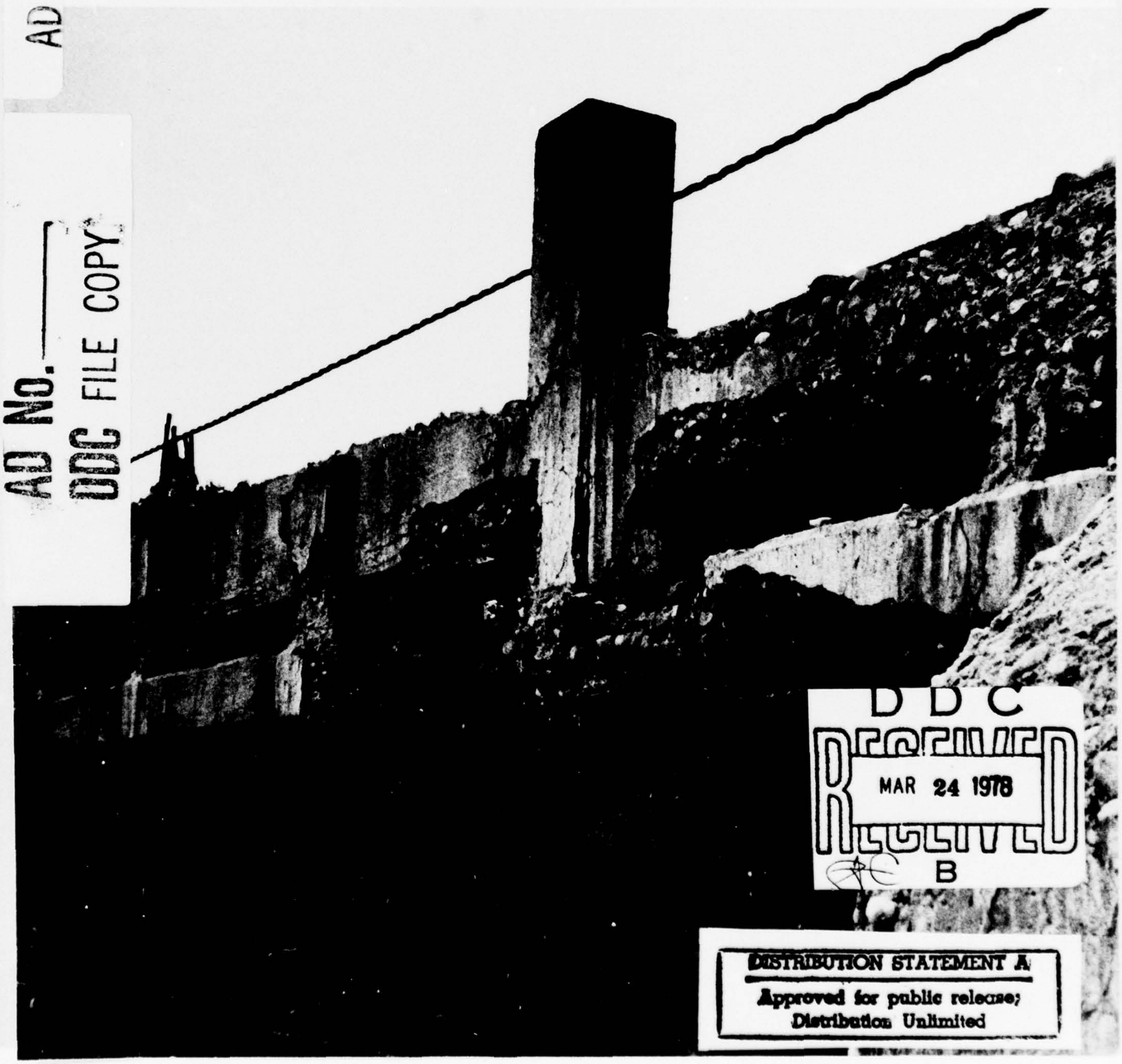

Cover: Extreme deterioration (spalling) of concrete bridge in high road salt usage area — U.S. Route 5, Norwich, Vermont. (Photograph by Peter Sector.)

CRREL Report 77-28

Freeze-thaw tests of liquid deicing chemicals on selected pavement materials

L. David Minsk

November 1977

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Tests were conducted to assess the extent of surface degradation resulting from the application of non-chloride deicing chemicals on three types of airfield pavements. The chemicals tested were proprietary mixtures of urea, formamide, and ethylene glycol; sodium chloride, distilled water, and dry specimens were used as controls and for comparison. Pavements included new and old specimens of open-graded asphaltic concrete and old specimens of dense-graded asphaltic concrete. Portland cement concrete specimens used were new and old, with and without air-entrainment. New and old tar rubber concrete specimens were also tested. Samples were subjected to up to 60 freeze-thaw cycles with deicing chemicals flooding their upper surface. Each specimen was rated on a scale of 0-5 after every five freeze-thaw cycles. All PCC specimens showed some surface degradation, whereas the dense- and over

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open-graded asphaltic concretes were largely unaffected.

PREFACE

This report was prepared by L. David Minsk, Research Physical Scientist, of the Applied Research Branch, Experimental Engineering Division, U.S. Army Cold Regions Research and Engineering Laboratory. Funding for this research was provided by U.S. Air Force Civil Engineering Center Project IE 2-72-1.

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Assisting with the laboratory work was Alan Zenkel. Specimens were obtained from existing pavements by Elwood Wells, Darryl Calkins, and Alan Zenkel.

The contents of this report are not to be used for advertising or promotional purposes. Citation of brand names does not constitute an official endorsement or approval of the use of such commercial products.

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ILLUSTRATIONS

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CONVERSION FACTORS: U.S. CUSTOMARY TO METRIC (SI) UNITS OF MEASUREMENTS

These conversion factors include all the significant digits given in the conversion tables in the ASTM *Metric Practice Guide* (E 380), which has been approved for use by the Department of Defense. Converted values should be rounded to have the same precision as the original (see E 380).

Multiply	*By*	*To obtain*
inch	25.4*	millimeter
foot	0.3048*	meter
$foot^2$	0.09290304*	$meter^2$
pound-mass	0.4535924	kilogram
pound-force/$inch^2$	6.894757	kilopascal
gallon	0.003785412	$meter^3$
degrees Fahrenheit	$t_{°C} = (t_{°F} - 32)/1.8$	degrees Celsius

* Exact

FREEZE-THAW TESTS OF LIQUID DEICING CHEMICALS ON SELECTED PAVEMENT MATERIALS

L. David Minsk

INTRODUCTION

Evidence that the common deicing chemicals, sodium chloride and calcium chloride, can cause surface deterioration of portland cement concrete (PCC) is well documented[1-7] (see cover). Less well demonstrated, however, is the effect of nonchloride deicing chemicals, particularly liquid chemicals, on the surface quality of both portland cement concretes and bituminous concretes. Evidence has been presented by Snyder[6] and Verbeck and Klieger[7] that scaling of the surface of PCC is primarily due to physical rather than chemical causes, resulting from the concentration gradient of the chemical which reverses the normal process of freezing from the outside in. However, liquids containing propylene glycol, ethylene glycol, urea, and formamide have been introduced as ice control chemicals on airfield runways to avoid the high corrosion rates on aircraft structural materials caused by chlorides, and the effects of many of these organic chemicals on pavements over a long period of time are unknown. The only previous investigation of any organic chemical was by Verbeck and Klieger[7] who included urea and ethyl alcohol along with sodium and calcium chlorides in their tests on scaling of PCC. It was the similar scaling of the PCC with both nonchloride and chloride chemicals that led them to conclude that the degradation mechanism was identical for both, and that low concentrations of chemicals (on the order of 2-4% by weight) caused the greatest scaling.

Several proprietary liquid chemicals containing organic compounds have been developed in the United States for use on airfield runways, some of which have been used on U.S. Air Force installations. The U.S. Air Force Civil Engineering Center, Tyndall AFB, Florida, requested CRREL to perform accelerated freeze-thaw tests using a number of these liquid deicing chemicals on typical new and old airfield runway pavements. This work was conducted in two test series between July 1972 and June 1973.

TEST PROCEDURE

The test procedure followed ASTM C 672-71T "Tentative method of test for scaling resistance of concrete surfaces to deicing chemicals" with some modifications. This method calls for 12- x 12- x 3-in. specimens; in this study specimens were either 6 x 8 x 3 in. or 6 x 10½ x 3 in. Specimens were covered with approximately ¼ in. of chemical solution held in place by wooden dikes sealed with General Electric RTV102 silicone rubber, then placed in a coldroom at 0°F for 16 hours, followed by thawing in the warm laboratory at 70°F for 8 hours. This cycle was repeated daily including weekends. At the end of every five freeze-thaw cycles, the deicing chemicals were poured off. The surface was rinsed first with tap water, then with distilled water, and the condition of the specimens was visually graded on a scale of 0-5, as shown in Table I. Distilled water was added as necessary to maintain the solution level at a depth of about ¼ in.

Table I. Visual rating scheme for scaling resistance.

Rating	*Surface condition*
0	No scaling
1	Very slight scaling (⅛-in. maximum depth, no coarse aggregate visible)
2	Slight to moderate scaling
3	Moderate scaling (some coarse aggregate visible)
4	Moderate to severe scaling
5	Severe scaling (coarse aggregate visible over entire surface)

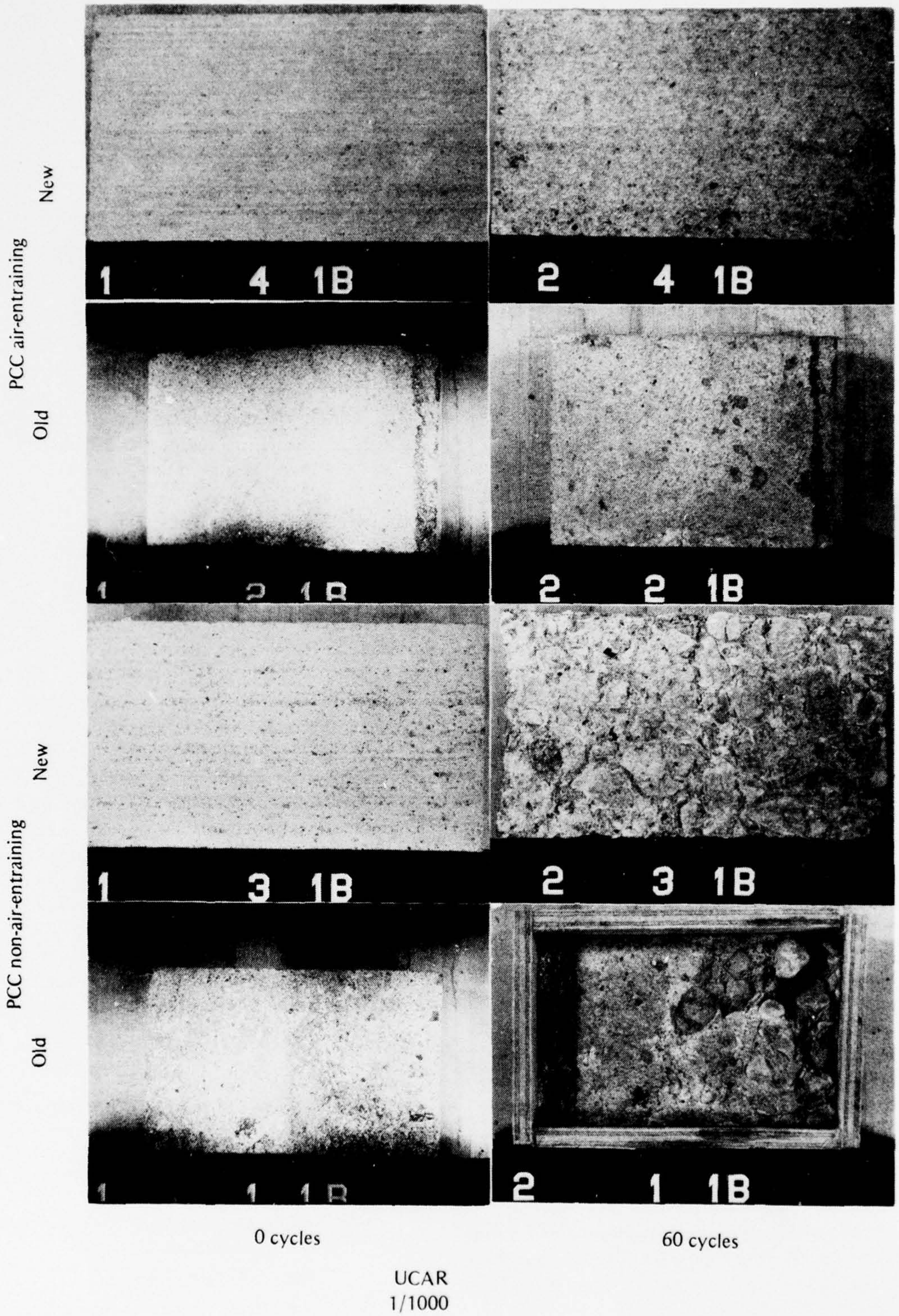


Figure 1. Typical photographs of PCC samples before testing and after 60 freeze-thaw cycles.

Figure 2. Movable rack. Specimens were moved in and out of coldroom in this way.

Photographs were taken of all specimens prior to covering them with the deicing chemicals, then midway through the test sequence (after 30 freeze-thaw cycles) and at the conclusion of the test. In those cases where the test had to be terminated prior to 60 cycles because of extreme deterioration, photographs were made at the time of termination. A typical photograph is shown in Figure 1. Figure 2 shows the rack used to hold and move the specimens in and out of the coldroom.

PAVEMENT TYPES

Tests were made on the materials listed in Table II. New portland cement concrete specimens were molded by the New England Division of the Corps of Engineers using an airfield mix design. Details on the aggregates, cement, mix design, curing and strength are given in Appendix B. Old PCC specimens were cut from runways at Wright-Patterson AFB, Ohio, but no history or mix design was available. Both new and old asphaltic concrete and tar rubber concrete specimens were furnished by the Air Force, again without any design or use history. The old porous friction asphalt specimens were cut from the runway at Pease AFB, New Hampshire. The dimensions of the specimens provided by the Air Force were 6 x 10½ x 3 in. Two replicates were used for each pavement/chemical combination.

Table II. Materials tested.

	New	*Old*
Air-entrained portland cement concrete	X	X
Non-air-entrained portland cement concrete	X	X
Dense-graded asphaltic concrete	X	X
Open-graded asphaltic concrete		X
Tar rubber concrete	X	X

DEICING CHEMICALS

Four proprietary liquid deicing chemicals and an Air Force deicing fluid were tested at concentrations specified by the Air Force on the basis of manufacturers' recommendations. These application rates are stated as spread rates: 1 gallon of undiluted deicing fluid per 1000 ft^2 and 2 gallons of deicing fluid per 1000 ft^2 (chosen according to ice thickness and temperature). These quantities were insufficient to cover the

Table III. Summary of PCC observations.

Chemical name	Symbol	Composition (principal constituents)	pH	Manufacturer	Concentration (gal./1000 ft^2)	Concentration (vol. %)	Type	Age	Series	Rating after 60 cycles	Cycles when surface rating reached 1	2	5	Average weight change (g/cm^2)	(%)
AF deicing fluid (MIL-A-8243B)	AF	Ethylene glycol-propylene glycol			1	1.7	non-air	old	1	1	25			+0.027	+0.16
								new	1	5	M	20	35	–0.69	–3.5
							air	old	1	1	35			+0.006	+0.03
								new	1	1	M			+0.043	+0.22
					2	3.4	non-air	old	1	1	25			+0.065	+0.34
								new	1	5	M	30	35	–1.66	–8.4
							air	old	1	1				+0.032	+0.15
								new	1	0				+0.069	+0.37
MCS 1082	MCS	Urea-formamide	7.6	Monsanto Co.	1	2.5	non-air	old	1	2	25	50		+0.053	+0.31
								new	1	5			20	–0.70	–3.5
							air	old	1	1	25			+0.018	+0.10
								new	1	2	20	25		–0.016	–0.085
					2	4.9	non-air	old	1	1	30			+0.058	+0.34
								new	1	5	M	M	20	–1.17	–5.9
							air	old	1	1	30			+0.005	+0.03
								new	1	2	20	40		+0.028	+0.15
UCAR runway deicer (PM-5197)	UCAR	Ethylene glycol-urea	9.1	Union Carbide Corp.	1	2.5	non-air	old	2	3	25	35		–0.57	–4.1
								new	2	5	5	10	30	–0.51	–2.4
							air	old	2	1	35			+0.076	+0.56
								new	2	1	5			+0.10	+0.51
					2	4.9	non-air	old	2	3	25	35		–0.38	–2.8
								new	2	3	5	15		–0.032	–0.16
							air	old	2	1	35			+0.13	+1.0
								new	2	1	5			+0.24	+1.2
NC 2207.1	NC	Propylene glycol	7.9	Dow Chemical Co.	1	2.5	non-air	old	2	3	20	35		–0.23	–1.7
								new	2	4	5	20		–0.18	–0.87
							air	old	2	1	35			+0.11	+0.40
								new	2	1	15			+0.14	+0.65
					2	4.9	non-air	old	2	4	25	35		–1.21	–8.0
								new	2	4	5	20		–0.32	–1.6
							air	old	2	1	35			+0.10	+0.74
								new	2	1	5			+0.24	+1.2
ISOLV	ISO	Urea-formamide	6.8	Kaiser Agricultural Chemicals, Inc.	1	2.5	non-air	old	2	3	25	30		–0.23	–1.5
								new	2	5	5	15	40	–0.63	–3.0
							air	old	2	1	40			+0.071	+0.51
								new	2	2	5	30		+0.075	+0.36
					2	4.9	non-air	old	2	5	25	35	50	–0.070	–4.6
								new	2	5	5	10	45	–0.51	–2.4
							air	old	2	1	30			+0.16	+1.1
								new	2	2	5	30		+0.13	+0.62
Ethylene glycol	EG	(reagent grade, L715)		J.T. Baker Co.	2	3.4	non-air	new	1	5	M	20	35	–2.0	–6.7
							air	new	1	1	M			–0.016	–0.07
Sodium chloride	SC	(reagent grade, S-271)		Fisher Scientific Co.	0.48 wt % (0.083 molal)		non-air	new	1	5	M	M	35	–1.5	–5.6
							air	new	1	1	M			+0.023	+0.09
Dry control							non-air	old	2	0				–0.032	–0.15
								new	2	0				–0.01	–0.04
							air	old	2	0				–0.058	–0.35
								new	2	0				+0.019	+0.08
Distilled water							non-air	new	1	0				–0.17	–0.60
							air	new	1	0				–0.019	–0.076
							non-air	old	2	0				–0.007	–0.086
								new	2	0				–0.18	+0.66
							air	old	2	0				+0.074	+0.34
								new	2	0				+0.18	+0.68

specimens to the desired ¼-in. depth (the application rate for 2 gal./1000 ft^2 works out to a depth of about 0.003 in.). Furthermore, merely placing twice as much undiluted fluid on the specimens would not change the concentration (concentration is an intensive variable). The assumption was made, therefore, that the deicing chemicals would be applied on a film of ice about $^1/_{16}$ in. thick with a water equivalent of 39 gal./1000 ft^2. The Air Force deicing fluid is normally diluted before spreading at the rate of 7 parts fluid to 3 parts water, so the test concentration was adjusted accordingly. In addition to these liquid deicing chemical mixtures, laboratory grade ethylene glycol and sodium chloride were also tested on some of the specimens. Concentration of the sodium chloride was based on an application rate of 400 lb of dry chemical per 2-lane (24-ft-wide) mile of highway covered with $^1/_8$ in. of ice. Controls were either dry specimens or specimens covered with distilled water.

Table III lists the chemicals used, their compositions and concentrations. The formulation of the proprietary chemicals is unknown, and neither molecular weight nor freezing point was determined.

DESCRIPTION OF TESTS

Two test series were run; thus, variability results from the different origins of the old pavement specimens and the different cements and aggregates used in molding the new PCC specimens. The first series consisted of tests on Air Force deicing fluid, Monsanto MCS 1082, laboratory grade ethylene glycol, sodium chloride, distilled water and a dry control. (The ethylene glycol, NaCl and distilled water were tested only on new PCC specimens since insufficient old specimens had been provided.) The second series was run on Union Carbide UCAR, Dow NC 2207.1, and Kaiser ISOLV, with distilled water and dry controls for all pavement types. A summary of the visual observations and weight changes for the PCC specimens is included in Table III. Table A1 is the complete listing of observations including the replicates; only averages of the surface ratings and weight changes are given in Table III. Figure 3 shows the surface ratings of the PCC specimens for all chemicals.

It was recognized in designing the experiment that depression of the freezing point by chemical action is only one factor in the surface deterioration of a pavement, and that abrasion from a blade or a steel-bristle broom may contribute significantly to pavement wear. An apparatus was constructed (Fig. 4) to simulate in the laboratory the scraping action of a blade. Specimens of new air-entrained PCC were mounted vertically in a movable carriage and pulled past a stationary blade 10 times after every five freeze-thaw cycles. Blade contact pressure was obtained by translating the load of a hanging weight to a horizontal force by a cable passing over a pulley. Materials lost during the wash-up following every five freeze-thaw cycles and the subsequent wet abrasion test were collected separately on a number 100 sieve, oven-dried, and weighed. Two sets of normal forces were applied to the blade: for the first 25 cycles (five abrasion tests) a 6- x $^1/_{16}$-in. aluminum blade was used with loads of 1 kg and 2 kg, giving contact pressures of 0.41 and 0.83 kgf/cm^2 (5.88 and 11.8 lbf/in.^{2}), respectively. When it was observed that very little concrete wear was occurring although the aluminum blade was wearing excessively, a 6- x $^1/_8$-in. steel blade was substituted and the loads increased to 5 and 10 kg, giving contact pressures of 1.03 and 2.07 kgf/cm^2 (14.7 to 29.4 lbf/in.^{2}), respectively. Two chemicals were used: UCAR (concentration 2/1000) and NaCl (the latter at only one force however).

The results are given in Table IV and Figure 5. The losses were very small, and surface condition ratings for all samples were 0 except for the last 10 cycles of the higher force UCAR specimens. Since losses did increase with higher blade contact pressure, abrasion is clearly a factor in surface degradation, though the degree of this influence has not been demonstrated by this test. However, abrasion should be considered seriously as an experimental parameter in any future tests.

DISCUSSION

Deterioration of the bituminous concrete specimens was insignificant; only an occasional piece of aggregate near the surface failed. Scaling of the portland cement concrete specimens was frequent with all chemicals used. The effects of age of sample and of air-entrainment were significant: old air-entrained specimens showed the least deterioration with the exception of one sample (new PCC exposed to AF deicing fluid at a concentration of 2/1000). Little effect was demonstrated by the concentrations of chemicals applied: in the low concentrations used, a factor of two in their levels was not significant.

A distinct odor of ammonia was detected during the rinsing of both urea-containing chemicals (Monsanto MCS 1082 and Kaiser ISOLV) from the PCC specimens. No such odor was detected with the asphaltic concrete specimens, suggesting that a

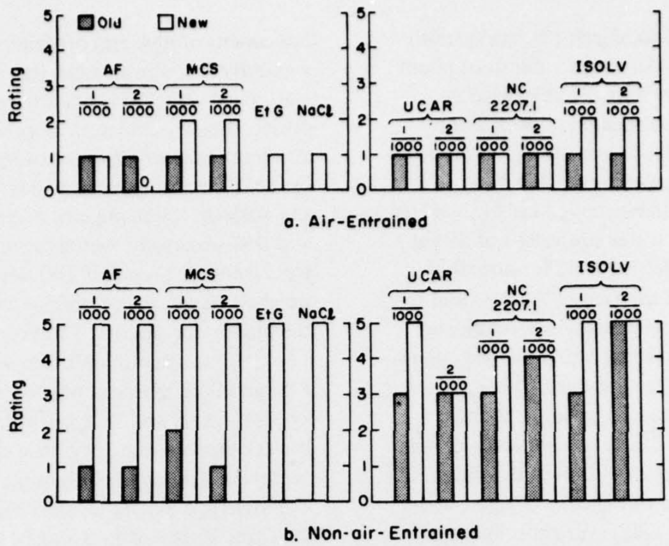
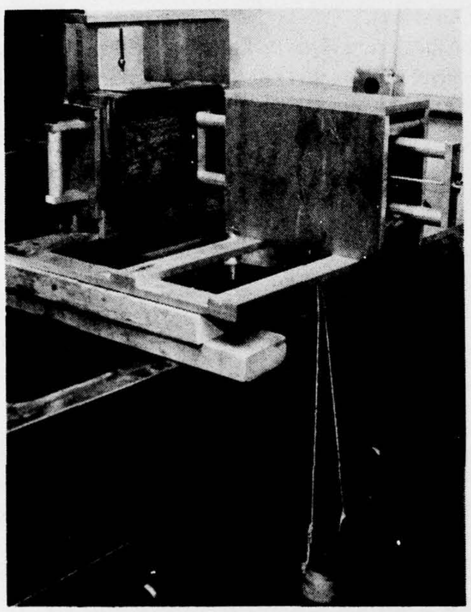


Figure 3. Terminal surface condition ratings of old and new air-entrained and non-air-entrained PCC specimens.



a. Apparatus placed on sink for test of a concrete specimen held vertically in sliding holder.

b. Apparatus is operated by pulling the specimen holder past the fixed blade loaded by a weight; material scraped by blade is collected in pan, dried, and weighed.

Figure 4. Abrasion apparatus.

Table IV. Abrasion test.

Weight loss (g)   W – wash-up; A – abrasion   S – Surface condition rating: 1-5

Force	Cycle chemical	5		10		15		20		25		30		35		40		45		50		55			60			Totals		
		W	A	W	A	W	A	W	A	W	A	W	A	W	A	W	A	W	A	W	A	W	A	S	W	A	S	W	A	W+A
1	UCAR	0.02	0.08	0.02	0.03	0.02	0.02	0.01	0.01	0.02	0.02	0.01	0.02	0.01	0.04	0.02	0.02	0.01	0.02	0.01	0.01	0.01	0.02	0	0.01	0.01	0	0.17	0.30	0.47
	UCAR	0.02	0.11	0.01	0.04	0.02	0.01	0.01	0.01	0.01	0.01	0.02	0.02	0.01	0.05	0.01	0.02	0.01	0.01	0.01	0.02	0.01	0.01	0	0.02	0.01	0	0.16	0.32	0.48
2	UCAR	0.02	.027	0.05	0.09	0.04	0.03	0.02	0.01	0.01	0.02	0.02	0.03	0.06	0.04	0.02	0.03	0.01	0.11	0.03	0.03	0.03	0.03	1	0.03	0.01	1	0.34	0.70	1.04
	UCAR	0.02	0.20	0.12	0.15	0.06	0.05	0.02	0.02	0.03	0.02	0.02	0.10	0.04	0.06	0.03	0.04	0.03	0.03	0.04	0.02	0.02	0.03	1	0.03	0.01	1	0.46	0.73	1.19
	NaCl	0.01	0.22	0.03	0.04	0.03	0.03	0.02	0.01	0.01	0	0.02	0.05	0.01	0.05	0.02	0.05	0.03	0.04	0.01	0.01	0.02	0.02	0	0.01	0.01	0	0.22	0.53	0.75

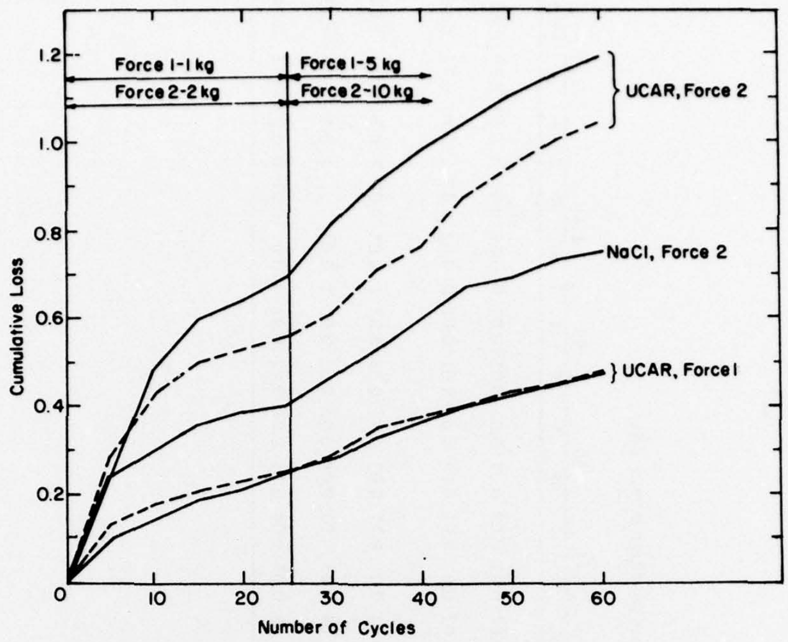


Figure 5. Cumulative loss from air-entrained PCC specimens by abrasion.

chemical reaction occurred with the PCC. There was no correlation between strength of odor and degree of deterioration, however.

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APPENDIX A: TEST RESULTS

Table A1. Results of freeze-thaw cycling tests; double entries (separated by a comma) are the values for replicates.

Chemical	Concentration (gal / 1000 ft^2)	Pavement type	Age	Surface condition rating										Wt. Change g(%)
				CYCLE 15	20	25	30	35	40	45	50	55	60	
AF deicing fluid	1/1000	PCC non-air-entrained	Old	0,0	0,0	1,1	1,1	1,1	1,1	1,1	1,1	1,1	1,1	+10(.16), +7(.15)
			New	M,M	1,2	1,2	2,2	5,5	5,5	5,5	5,5	5,5	5,5	-260(3.2), -302(3.8)
		PCC air-entrained	Old	0,0	0,0	0,0	0,0	0,1	0,1	0,1	0,1	0,1	0,1	-8(.15), +12(.21)
			New	M	1,1	1,1	1,1	1,1	1,1	1,1	1,1	1,1	1,1	+20(.26), +15(.19)
		Asphaltic concrete	Old	0,0									0,0	+4(.11), +11(.28)
			New	0,0									0,0	+8(.16), +10(.21)
		Tar rubber concrete	Old	0,0									0,0	+12(.33), -17(.53)
			New	0,0	0,0	0,0	0,0	0,0	1,0	1,0	1,0	1,0	1,1	+4 (.15), 0
	2/1000	PCC non-air-entrained	Old	0,0	0,0	0,1	1,1	1,1	1,1	1,1	1,1	1,1	1,1	+21(.34), +18(.33)
			New	M,M	1,1	1,1	2,2	5,5	5,5	5,5	5,5	5,5	5,5	-984(12.3), -364(4.5)
		PCC air-entrained	Old	0,0	0,0	0,0	0,0	1,1	1,1	1,1	1,1	1,1	1,1	+7(.11), +12(.19)
			New	M	0,0								0,0	+28(.36), +28(.37)
		Asphaltic concrete	Old	0,0									0,0	+14(.35), +18(.44)
			New	0,0									0,0	+45(.88), +45(.90)
		Tar rubber concrete	Old	0,0									0,0	+2(.06), +14(.38)
			New	0,0									0,0	+5(.18), +11(.40)

Table A1 (cont'd). Results of freeze-thaw cycling tests; double entries (separated by a comma) are the values for replicates.

Chemical	Concentration (gal / 1000 ft^2)	Pavement Type	Age	Surface condition rating — Cycle 15	20	25	30	35	40	45	50	55	60	Wt. Change g(%)
MCS 1082	1/1000	PCC non-air-entrained	Old	0,0	0,0	0,1	1,1	1,1	1,1	1,1	1,2	1,2	1,2	+26(.49), +7(.13)
			New	4,4	5,5	5,5	5,5	* x	x	x	x	x	x	-294(3.6), -277(3.4)
		PCC air-entrained	Old	0,0	0,0	0,1	0,1	0,1	0,1	0,1	0,1	0,1	0,1	+3 (.05), +8 (.14)
			New	M	1,1	2,2	2,2	2,2	2,2	2,2	2,2	2,2	2,2	-5 (.06), -8 (.11)
		Asphaltic concrete	Old	0,0									0,0	+3 (.07), 0
			New	0,0									0,0	-5 (.10), -4 (.08)
		Tar rubber concrete	Old	0,0									0,0	+2 (.05), +4 (.11)
			New	1,1	1,1	1,1	1,1	1,1	1,1	1,1	1,1	1,1	1,1	0 , -5 (.19)
	2/1000	PCC non-air-entrained	Old	0,0	0,0	0,0	1,1	1,1	1,1	1,1	1,1	1,1	1,1	+16(.29), +20(.39)
			New	4,4	5,5	5,5	5,5	5,5	* x	x	x	x	x	-479(5.9), -475(5.8)
		PCC air-entrained	Old	0,0	0,0	0,0	1,1	1,1	1,1	1,1	1,1	1,1	1,1	-5 (.08), +8 (.14)
			New	M	1,1	1,1	1,1	1,1	2,2	2,2	2,2	2,2	2,2	+12(.15), +11(.14)
		Asphaltic concrete	Old	0,0	0,0	0,0	1,1	1,1	1,1	1,1	1,1	1,1	1,1	-1 (.02), +2 (.05)
			New	0,0									0,0	+4 (.08), +12(.24)
		Tar rubber concrete	Old	0,0									0,0	+3 (.09), +4 (.12)
			New	1,0	1,0	1,0	1,0	1,0	1,1	1,1	1,1	1,1	1,1	+4 (.16), +2 (.07)
Ethylene glycol (lab grade)		PCC non-air-entrained	New	M	2	3	3	5	5	5	5	5*	x	-626(6.7)
		PCC air-entrained	New	M	1	1	1	1	1	1	1	1	1	-5 (.07)
Sodium chloride (NaCl--lab grade)		PCC non-air-entrained	New	M	4	4	4	5	5	5	5	5	5	-457(5.6)
		PCC air-entrained	New	M	1	1	1	1	1	1	1	1	1	+7 (.09)
Distilled water		PCC non-air-entrained	New	M	0								0	-53(.6)
		PCC air-entrained	New	M	0								0	-6 (.08)
Dry Control		PCC non-air-entrained	Old	0									0	-10 (.15)
			New	0									0	-3 (.04)
		PCC air-entrained	Old	0									0	-18 (.35)
			New	0									0	+6 (.08)
		Asphaltic concrete	Old	0									0	-8 (.20)
			New	0									0	-5 (.10)
		Tar rubber concrete	Old	0									0	-6 (.17)
			New	0									0	-2 (.07)

* Test terminated at this point because of extreme deterioration of specimen.

Table A1 (cont'd).

Chemical	Concentration (gal/1000 ft^2)	Pavement type	Age	Surface condition rating												Wt. Change g(%)
				5	10	15	20	25	30	35	40	45	50	55	60	
				CYCLE												
UCAR	1/1000	PCC non-air-entrained	Old	0,0	0,0	0,0	0,0	1,1	1,1	2,2	3,3	3,3	3,3	3,3	3,3	-187(4.4), -168(3.9)
			New	1,1	2,1	2,2	3,2	4,3	5,4	5,4	5,4	5,4	5,4	5,5	5,5	-266(3.1), -149(1.7)
		PCC air-entrained	Old	0,0	0,0	0,0	0,0	0,0	0,0	1,1	1,1	1,1	1,1	1,1	1,1	+30(.72), +17(.40)
			New	1,1	1,1	1,1	1,1	1,1	1,1	1,1	1,1	1,1	1,1	1,1	1,1	+48(.57), +37(.44)
		Asphaltic concrete	Old	0,0											0,0	+20(.36), +13(.29)
			New	0,0											0,0	+3(.15), +1(.04)
		Tar rubber concrete	Old	0,0											0,0	+5(.10), +16(.34)
			New	0,0											0,0	+6(.12), +14(.34)
		Porous friction concrete	-	0,0											0,0	+34(2.4), +24(1.8)
	2/1000	PCC non-air-entrained	Old	0,0	0,0	0,0	0,0	1,1	1,1	2,2	2,2	2,2	2,2	2,2	3,3	-167(3.9), -68(1.7)
			New	1,1	1,1	2,2	2,2	2,2	2,2	2,2	2,2	2,2	2,2	2,2	2,3	+13(.15), -39(.46)
		PCC air-entrained	Old	0,0	0,0	0,0	0,0	0,0	0,0	1,1	1,1	1,1	1,1	1,1	1,1	+48(1.1), +35(.98)
			New	1,1	1,1	1,1	1,1	1,1	1,1	1,1	1,1	1,1	1,1	1,1	1,1	+105(1.3), +94(1.1)
		Asphaltic concrete	Old	0,0											0,0	+31(.60), +25(.51)
			New	0,0											0,0	+19(.83), +13(.60)
		Tar rubber concrete	Old	0,0											0,0	+19(.41), +22(.45)
			New	0,0											0,0	+18(.45), +25(.62)
		Porous friction concrete	-	0,0											0,0	+27(1.7), +28(1.8)
NC 2207.1	1/1000	PCC non-air-entrained	Old	0,0	0,0	0,0	0,0	1,1	1,1	2,2	3,3	3,3	3,3	3,3	3,3	-89(2.1), -54(1.3)
			New	1,1	1,1	1,1	1,2	1,2	2,3	2,3	2,3	2,4	2,4	2,4	2,4	+23(.26), -167(2.0)
		PCC air-entrained	Old	0,0	0,0	0,0	0,0	0,0	0,0	1,1	1,1	1,1	1,1	1,1	1,1	+19(.52), +14(.28)
			New	0,0	0,0	1,1	1,1	1,1	1,1	1,1	1,1	1,1	1,1	1,1	1,1	+33(.40), +77(.90)
		Asphaltic concrete	Old	0,0											0,0	+18(.36), +19(.39)
			New	0,0											0,0	+8(.39), +7(.32)
		Tar rubber concrete	Old	0,0											0,0	+19(.37), +23(.45)
			New	0,0											0,0	+21(.44), +17(.39)
		Porous friction concrete	-	0,0											0,0	+24(1.9), +28(2.2)
	2/1000	PCC non-air-entrained	Old	0,0	0,0	0,0	0,0	1,1	1,1	2,2	2,2	2,2	2,2	3,3	3,4	-252(5.4), -497(.11)
			New	0,1	0,1	1,1	1,2	1,2	1,2	1,2	2,3	2,3	3,3	3,3	4,3	-100(1.2), -161(1.9)
		PCC air-entrained	Old	0,0	0,0	0,0	0,0	0,0	0,0	1,1	1,1	1,1	1,1	1,1	1,1	+42(.94), +22(.53)
			New	1,1	1,1	1,1	1,1	1,1	1,1	1,1	1,1	1,1	1,1	1,1	1,1	+92(1.1), +99(1.2)
		Asphaltic concrete	Old	0,0											0,0	+40(.76), +60(1.2)
			New	0,0											0,0	+17(.85), +24(1.1)
		Tar rubber concrete	Old	0,0											0,0	+9(.19), +12(.26)
			New	0,0											0,0	+200(4.2), +43(1.1)
		Porous friction concrete	-	0,0											0,0	+33(2.0), +23(1.9)

Table A1 (cont'd). Results of freeze-thaw cycling tests; double entries (separated by a comma) are the values for replicates.

Chemical	Concentration (gal/1000 ft^2)	Pavement type	Age	Surface condition rating												Wt. Change g(%)
				CYCLE 5	10	15	20	25	30	35	40	45	50	55	60	
ISOLV	1/1000	PCC non-air-entrained	Old	0,0	0,0	0,0	0,0	1,1	2,2	3,3	3,3	3,3	3,3	3,3	3,3	-79(1.6), -65(1.3)
			New	1,1	1,1	2,2	2,2	3,3	4,4	4,4	4,5	5,5	5,5	5,5	5,5	-248(2.9), -263(3.0)
		PCC air-entrained	Old	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,1	0,1	0,1	0,1	0,1	+34(.79), +10(.22)
			New	1,1	1,1	1,1	1,1	1,1	2,2	2,2	2,2	2,2	2,2	2,2	2,2	+31(.36), +30(.36)
		Asphaltic concrete	Old	0,0											0,0	+30(.64), +13(.25)
			New	0,0											0,0	+62(2.3), +38(1.7)
		Tar rubber concrete	Old	0,0											0,0	+24(.47), +26(.52)
			New	0,0											0,0	+104(2.2), +165(3.1)
		Porous friction concrete	-	0,0											0,0	+20(1.4), +19(1.5)
	2/1000	PCC non-air-entrained	Old	0,0	0,0	0,0	0,0	1,1	1,2	2,3	2,3	2,4	2,5*	2,x	3,x	-73(1.6), -362(7.7)
			New	1,1	2,1	2,2	2,2	3,2	4,3	4,3	4,3	5,3	5,4	5,4	5,4	-247(2.9), -165(1.9)
		PCC air-entrained	Old	0,0	0,0	0,0	0,0	0,0	0,1	0,1	0,1	0,1	0,1	0,1	0,1	+45(1.1), +51(1.1)
			New	0,1	1,1	1,1	1,1	1,1	2,2	2,2	2,2	2,2	2,2	2,2	2,2	+44(.53), +61(.72)
		Asphaltic concrete	Old	0,0											0,0	+42(.77), +45(.96)
			New	0,0											0,0	+83(3.2), +53(2.2)
		Tar rubber concrete	Old	0,0											0,0	+35(.68), +53(.97)
			New	0,0											0,0	+137(3.2), +150(3.4)
		Porous friction concrete	-	0,0											0,0	+24(1.9), +42(3.2)
Distilled Water	-	PCC non-air-entrained	Old	0											0	-3(.09)
			New	0											0	+58(.67), +56(.65)
		PCC air-entrained	Old	0											0	+18(.43), +11(.26)
			New	0											0	+53(.63), +60(.73)
		Asphaltic concrete	Old	0											0	+32(.60), +23(.43)
			New	0											0	+8(.41), +18(.78)
		Tar rubber concrete	Old	0											0	+9(.19), +10(.21)
			New	0											0	+5(.13), +9 (.22)
		Porous friction concrete	-	0											0	+24(1.9), +28(1.7)
Dry Control		PCC non-air-entrained	Old	-											-	-26(.62)
			New	-											-	-21(.26)
		PCC air-entrained	Old	-											-	-11(.40)
			New	-											-	-25(.32)
		Asphaltic concrete	Old	-											-	-7 (.15)
			New	-											-	+1 (.05)
		Tar rubber concrete	Old	-											-	-10 (.23)
			New	-											-	-1 (.03)
		Porous friction concrete	-	-											-	-

* Test terminated at this point because of extreme deterioration of specimen.

APPENDIX B: PORTLAND CEMENT CONCRETE MATERIALS DATA

SUMMARY SHEET - LABORATORY CONCRETE MIX DESIGN

PROJECT Preparation of Concrete Specimens for Sealing Resistance Tests	CONTRACT NO U.S. Army CRREL Work Order No.	MIX NO CR	TYPE MIX Airfield Pavement Concrete	TESTING LABORATORY NED Laboratory	DATE June 1972

FINE AGGREGATE	COARSE AGGREGATE	CEMENT	AIR ENTRAINMENT AGENT
TYPE Processed Natural Sand LAB. SERIAL NO 76-282-1 SOURCE Atlantic Coast Aggregates Woodbury New York	TYPE Crushed Quarry Stone SIZES 1-1/2" LAB. SERIAL NOS 76-280-1 3/4" 76-280-2 SOURCE Appalachian Stone Co Haverstraw, N. Y. BLEND 50%-1-1/2" and 50%-3/4"	TYPE I Portland BRAND Atlas LAB.SER.NO 76-281-4 SOURCE Universal Atlas Cement Co Northampton, Pa.	BRAND "AIRECON" LAB.SER.NO 76-280-4 SOURCE Chemsorb Inc. Summit, New Jersey

DESIGN DATA					TRIAL MIXTURE DATA												TEST RESULTS ON HARDENED CONCRETE					
							TEMPERATURE (° F)								AIR CONT. (%)		AT AGE 7 DAYS		AT AGE 14 DAYS		AT AGE 28 DAYS	
CEMENT FACTOR (CWT/CY)	WATER-CEMENT RATIO	SAND FACTOR % BY VOLUME	AIR ENTRAINMENT ADDED (OZ./CWT)	ABSOLUTE VOL. (CF per CY)	SYMBOLS BEAMS SPECIMENS PER BATCH (6"x6"x21")	DATE MADE	MIXING WATER	LABORATORY	CONCRETE	WORKABILITY AND BLEEDING	SLUMP (INCHES)	WET DENSITY OF CONCRETE (PCF)	YIELD (CF per CY)	CORRECTED CEMENT FACTOR (CWT/CY)	METER	GRAVI-METRIC	SPECIMEN NO.	COMPR. STRENGTH (PSI)	SPECIMEN NO.	COMPR. STRENGTH (PSI)	SPECIMEN NO.	THIRD PT. L'D'G FLEXURAL STRENGTH (PSI)
5.64	0.42	32.1	2.8	25.380	CR-1 thru CR-7	10 May 1972	72	78	73	Good-Negligible Bleeding	1.5	152.2	26.76	5.69	5.1	5.2					CR-6	740
																					CR-7	690
																					Average	715
6.40	0.42	33.7	0	26.730	CR-8 thru CR-14	10 May 1972	72	77	74	Very Good Very Slight Bleeding	2.25	157.1	27.10	6.38	1.6	1.4					CR-13	930
																					CR-14	875
																					Average	900

(1) Beams cast in accordance with CRD-C10, Method of Making and Curing Concrete Test Specimens in The Laboratory, for Beam Specimens for Test in Flexure by Third Point Loading. Concrete consolidated with vibrator.

(2) Surface of beams finished initially in accordance with CRD-C10, then after bleeding stopped, the surface of the concrete was refinished with a wood float followed with a burlap drag final finish.

(3) Beams were covered with wet burlap immediately after initial setting time of about 3 hours. This was done to prevent damage to surface of the concrete. Beams kept covered with wet burlap until time of stripping.

(4) Beams removed from molds at age 48 hours and placed in limed water. Beams CR-1 thru CR-5 and CR-8 thru CR-12 removed from water at age 14 days and stored at room temperature 70 -80 F, and 50% relative humidity for 8 days (1 June 1972) at which time they were cut to specimen size for future testing. Cut specimens stored at room temperature same as beams until picked up by CRREL. Beams CR-6, CR-7, CR-13 and CR-14 removed from limed water at age 28 days and tested for flexural strength.

BATCH WEIGHTS PER CU. YD.	CR-1-7	CR-8-14
Cement	564#	640#
3/4" Stone(*)	1150#	1150#
1-1/2" Stone(*)	1140#	1140#
Sand (*)	982#	1057#
Water (**)	237#	269#
AE Agent	15.8 oz	0

NOTES AND OR REMARKS

(*) Saturated Surface Dry weights
(**) Does not inculde water of absorption in aggregates.

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SUMMARY SHEET - LABORATORY CONCRETE MIX DESIGN

PROJECT	CONTRACT NO	MIX NO	TYPE MIX	TESTING LABORATORY	DATE
CRREL Deicing Project, Preparation of Concrete Specimens	CRREL Work Order No. 73-25	CR	Airfield Pavement Concrete	New England Division	December 1972

FINE AGGREGATE	COARSE AGGREGATE	CEMENT	AIR ENTRAINMENT AGENT
TYPE Processed Natural Sand LAB. SERIAL NO 50-133-3 SOURCE Atlantic Coast Aggregates	TYPE Crushed Quarry Stone SIZES: 1½" (LAB. SERIAL NOS 50-133-1); 3/4" (50-133-2) SOURCE Appalachian Stone Co Haverstraw, N.Y. BLEND 45% - 1½" and 55%-3/4"	TYPE I Portland BRAND Martin-Marietta LAB.SER.NO 76-290-4 SOURCE Martin-Marietta Cement Northamton, Pa (1)	BRAND "AIRECON" LAB.SER.NO 76-290-5 SOURCE Chemsorb Inc., Summit, New Jersey

DESIGN DATA					TRIAL MIXTURE DATA													TEST RESULTS ON HARDENED CONCRETE					
					SYMBOLS		TEMPERATURE (° F)								AIR CONT. (%)			AT AGE 7 DAYS		AT AGE 14 DAYS		AT AGE 28 DAYS	
CEMENT FACTOR (CWT/CY)	WATER-CEMENT RATIO	SAND FACTOR % BY VOLUME	AIR ENTRAINMENT ADDED (OZ./CWT.CEM.)	ABSOLUTE VOL. (CF per CY)	CYLINDER SPECIMENS PER BATCH	DATE MADE	MIXING WATER	LABORATORY	CONCRETE	WORKABILITY AND BLEEDING	SLUMP (INCHES)	WET DENSITY OF CONCRETE (PCF)	YIELD (CF per CY)	CORRECTED CEMENT FACTOR (CWT/CY)	METER	GRAVI-METRIC	SPECIMEN NO.	COMPR. STRENGTH (PSI)	SPECIMEN NO.	COMPR. STRENGTH (PSI)	SPECIMEN NO.	THIRD PT. L'D'G FLEXURAL STRENGTH (PSI)
5.64	0.42	32.4	1.1	25.413	CR-26 thru CR-30	11 Dec. 1972	75	72	74	Good - Negligible Bleeding	3.0	152.8	26.72	5.70	4.5	4.9						
5.64	0.42	32.6	1.5	25.318	CR-31 thru CR-36	11 Dec. 1972	75	72	73	ditto	2.75	152.0	26.75	5.69	5.0	5.4					CR-36	775
6.40	0.42	33.9	0	26.730	CR-15 thru CR-19	11 Dec.1972	74	72	74	Poor Negligible Bleeding	2.0	157.9	26.99	6.40	1.2	1.0						
6.40	0.43	33.9	0	26.829	CR-20 thru CR-25	11 Dec. 1972	72	72	74	Good - Negligible Bleeding	3.0	156.7	27.24	6.34	1.1	1.5					CR-25	790

NOTES

(1) Martin-Marietta Type I Portland cement was available in laboratory at time beams were cast. Unable to obtain Atlas Type I Cement from Northampton, Pa in time to meet CRREL testing schedule. Atlas Cement Company representative was contacted, and his opinion was that Martin-Marietta Type I Cement from Northampton, Pa. is similar to their cement from the same area.

(2) Beams cast, finished, and initially cured and stripped same as Beams CR-1 thru CR-14 fabricated on 10 May 1972

(3) After stripping, all beams placed in limed water and removed from water at the end of 15 days (26 Dec.1972) and stored at room temperature 70-75F and 50% Relative Humidity for 8 days (3 January 1973) at which time beams were sawed to specimen sizes. Cut specimens stored at room temperature and humidity as beams until picked up by CRREL representative

MATERIAL	BATCH WEIGHTS PER CU. YD. CR-26-36	CR-15-25
3/4" Stone (*)	1260#	1260#
1-1/2" Stone (*)	1025#	1025#
Sand (*)	998#	1067#
Cement	564#	640#
Water (**)	237#	269#
Air Entrainment	6 to 8 oz	0

(*) Saturated Surface Dry Weights
(**) Does not include water of absorption in aggregates

NOTES AND OR REMARKS

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AGGREGATE TEST RESULTS

PROJECT: CRREL Deicing Project SPECIFICATION NO.

REQUIRED USE: Preparation of Concrete Specimens CONTRACT NO.

TYPE MATERIAL: Fine Concrete Aggregate CLASSIFICATION: Processed Natural Sand

SOURCE: Atlantic Coast Aggregates LOCATION: Woodbury, New York

TESTING AGENCY: NED Laboratory PROJECT LAB. NO. 73-JO-1

MECHANICAL ANALYSIS PER CENT PASSING, BY WEIGHT

Sieve Designation	Sample Lab. No. 50-133-3		76-282-1 (*)			
3-inch						
2-1/2-inch						
2-inch						
1-1/2-inch						
1-inch						
3/4-inch						
1/2-inch						
3/8-inch						
No. 4	100		100			
No. 8	88		87			
No. 16	74		69			
No. 30	56		48			
No. 50	31		24			
No. 100	7		5			
No. 200	1		2			

PHYSICAL PROPERTIES

Fineness Modulus	2.44		2.67			
Specific Gravity						
Bulk Oven Dry	2.57		2.56			
Bulk S.S. Dry	2.63		2.62			
Apparent	2.73		2.72			
Absorption %	2.3		2.3			
Organic Color Test						
L.A. Abrasion Test (% Loss - 500 Rev.)						
Soundness ($MgSO_4$) (% Loss - 5 cycles)						
Flat & Elongated Particles (% by Wt. - 3 to 1 Ratio)						
Cube Compressive Strength						
% of Stand. 3-Days						
% of Stand. 7-Days						
% of Stand. 28-Days						

(*) Data for material used in fabricating original specimens on 10 May 1972

R.J. Strong

R.J.STRONG, Chief, NED Laboratory

SIGNATURE:

8 January 1973

DATE:

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AGGREGATE TEST RESULTS

PROJECT: CRREL Deicing Project SPECIFICATION NO. ______

REQUIRED USE: Preparation of Concrete Specimens CONTRACT NO. ______

TYPE MATERIAL: Coarse Concrete Aggregates CLASSIFICATION: Crushed Quarry Stone

SOURCE: Appalachian Stone Co. LOCATION: Haverstraw, New York

TESTING AGENCY: NED Laboratory PROJECT LAB. NO. 73-JO-1

MECHANICAL ANALYSIS PER CENT PASSING, BY WEIGHT

Sieve Designation	Sample Lab. No.					
	50-133-1	76-280-1	50-133-2	76-280-2	As Blended for Mix	
	1½"	1½" (*)	3/4"	3/4" (*)	133-1 & 2	(*)
3 - inch						
2-1/2-inch						
2- inch						
1-1/2-inch	100	100			100	100
1 - inch	55	53	100	100	80	77
3/4-inch	3	7	94	98	54	53
1/2-inch	1	3	62	73	35	38
3/8-inch	1	2	29	50	16	26
No. 4	1	1	4	4	2	6
No. 8						
No. 16						
No. 30						
No. 50						
No. 100						
No. 200						

PHYSICAL PROPERTIES

Fineness Modulus						
Specific Gravity						
Bulk Oven Dry						
Bulk S. S. Dry						
Apparent						
Absorption %						
Organic Color Test						
L. A. Abrasion Test (% Loss – 500 Rev.)						
Soundness ($MgSO_4$) (% Loss – 5 cycles)						
Flat & Elongated Particles (% by Wt.-3 to 1 Ratio)						
Cube Compressive Strength						
% of Stand. 3-Days						
% of Stand. 7-Days						
% of Stand. 28-Days						

(*) Gradation of materials used in fabricating original specimens on 10 May 1972

R.J. Strong

R.J. STRONG, Chief, NED Laboratory
SIGNATURE:

8 January 1973
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